CHARACTERISTICS AND ABSORPTION COEFFICIENT OF CO$_2$ LASER IN NATURAL GAS MIXTURES

By

NORHAFIDZAH BINTI MOHD SAAD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirement for the Degree of Master of Science

April 2006
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DEDICATION

To my beloved husband and son.
Characteristics and Absorption Coefficient of CO$_2$ Laser in Natural Gas Mixtures

By

NORHAFIDZAH BINTI MOHD SAAD

April 2006

Chairman: Associate Professor Ir Norman Mariun, PhD

Faculty: Engineering

This work was arranged to develop scientific and engineering database on the study of cw / repetitively pulsed CO$_2$ laser in terms of its characteristics and absorption coefficient in natural gas mixtures. The laser system is operated both in continuous wave mode as well as in pulse mode at 10.6µm wavelength range of infrared electromagnetic spectrum.

The study on CO$_2$ laser system consists of two parts. In the first part, the measurements on the characteristics of cw / repetitively pulsed CO$_2$ laser system are done at 10.6 µm wavelength. The output parameters of CO$_2$ laser are carried out in detail to determine the laser characteristics for getting maximum output energy and power subject to various variable such as pulse repetition rate, discharge current, duty cycle and pulse duration. Different aspects of CO$_2$ laser are studied to determine the laser characteristics between various design parameters and the effect of varying one parameter on others. The frequency and current
limits regarding maximum and minimum output energy and power are presented. The maximum pulse energy is achieved at 32mJ when the laser operated at 10mA discharge current with 50 Hz pulse repetition rate. A maximum power of about 11 watts is measured at a current of 10mA. The output energy and power is found to decrease with further increase in pulse repetition rate and discharge current. This is due to the saturation of the gas molecules inside the laser tube.

In the second part of the project, the experimental work on the absorption coefficient of CO$_2$ laser in compressed natural gas mixtures are measured at variable laser energy and pressures operated at 295K temperature. The measurements are done using optical transmission loss technique with 19% transmission loss due to the absorption by the optical system. The absorption data showed a strong dependence on both laser energy and pressure. It was found that natural gas mixtures absorb laser light the most, followed by pure natural gas and the lowest laser absorption coefficient is air. The results are found to follow the exponential law of absorption that is called as Beer-Lambert Law.

The purpose of this study is to explore the application of CO$_2$ laser especially in the area of combustion of natural gas. For the first step, the characteristics in terms of laser energy and power and its absorption in natural gas need to be studied.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

CIRI-CIRI DAN PEMALAR PENYERAPAN LASER CO$_2$ DI DALAM CAMPURAN GAS ASLI

Oleh

NORHAIFDZAH BINTI MOHD SAAD

April 2006

Pengerusi: Profesor Madya Ir Norman Mariun, PhD
Fakulti: Kejuruteraan

Kajian ini bertujuan untuk membangunkan data-data saintifik dan kejuruteraan terhadap ciri-ciri sistem laser CO$_2$ serta pemalar penyerapan laser tersebut terhadap campuran gas asli. Sistem laser CO$_2$ yang beroperasi secara gelombang terus atau denyut berkala telah dilakukan pada panjang gelombang 10.6 µm pada spektrum electromagnet infra-merah.

beroperasi pada arus 10mA dengan frekuensi 50Hz iaitu sebanyak 32mJ. Kuasa maksima pula diperolehi sebanyak 11 watt iaitu pada arus 10mA. Selepas melepasi nilai tenaga dan kuasa maksima tersebut, keluaran tenaga dan kuasa didapati berkurang dengan pertambahan frekuensi dan arus. Ini disebabkan molekul gas di dalam tiub laser menjadi tepu.


Tujuan kajian ini adalah untuk mengkaji penggunaan laser CO\textsubscript{2} terutama di dalam penyelidikan berkaitan pembakaran gas asli. Sebagai langkah pertama, ciri-ciri sistem laser CO\textsubscript{2} dan pemalar penyerapan terhadap gas asli perlu dikaji.
ACKNOWLEDGEMENTS

First of all, with the humble gratitude, I would like to express my thanks and deepest praise to The Most Gracious and Most Merciful ALLAH Who has given me all strength, faith, confidence and patience to complete this project.

It would be my pleasure to express my most sincere thanks to my supervisor Assoc. Prof. Ir Dr. Norman Mariun and members of my supervisor committee Assoc. Prof. Dr. Nasrullah Khan and Pn. Nurul Amziah for their advice, understanding, support, criticism, guidance and co-operation in completing this thesis.

I would like to express my appreciation to Kolej Universiti Kejuruteraan & Teknikal Malaysia (KUKTEM) for their generous financial support. Without them, this thesis would be a great burden.

Finally, I would like to thank Universiti Putra Malaysia, my family and all my friends especially my husband, Muhammad Fadhil Abas for their support. I pray to Allah that He rewards each a bountiful reward.
I certify that an Examination Committee has met on 12 April 2006 to conduct the final examination of Norhafidzah binti Mohd Saad on her Master of Science thesis entitled “Characteristics and Absorption Coefficient of CO$_2$ Laser in Natural Gas Mixtures” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follow:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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Date:
DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledge. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

NORHAFIDZAH BINTI MOHD SAAD

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<tr>
<td>B</td>
<td>rotational constant</td>
</tr>
<tr>
<td>c</td>
<td>velocity of light</td>
</tr>
<tr>
<td>CNG</td>
<td>compressed natural gas</td>
</tr>
<tr>
<td>CH₄</td>
<td>methane</td>
</tr>
<tr>
<td>cw</td>
<td>continuous wave</td>
</tr>
<tr>
<td>d</td>
<td>beam diameter</td>
</tr>
<tr>
<td>DC</td>
<td>duty cycle</td>
</tr>
<tr>
<td>DPDT</td>
<td>double poles double throw</td>
</tr>
<tr>
<td>E</td>
<td>laser energy</td>
</tr>
<tr>
<td>E_{abs}</td>
<td>absorbed laser energy</td>
</tr>
<tr>
<td>E_{i}</td>
<td>excitation energy</td>
</tr>
<tr>
<td>E_{m}</td>
<td>measured laser energy</td>
</tr>
<tr>
<td>E_{r}</td>
<td>rotational energy</td>
</tr>
<tr>
<td>E_{tr}</td>
<td>transmitted laser energy</td>
</tr>
<tr>
<td>E_{trans}</td>
<td>transition energy</td>
</tr>
<tr>
<td>E_{v}</td>
<td>vibrational energy</td>
</tr>
<tr>
<td>E_{o}</td>
<td>initial laser energy</td>
</tr>
<tr>
<td>FIR</td>
<td>far-infrared</td>
</tr>
<tr>
<td>F_{ph}</td>
<td>photon flux</td>
</tr>
<tr>
<td>F_{E}</td>
<td>electric field</td>
</tr>
<tr>
<td>f</td>
<td>focal length</td>
</tr>
<tr>
<td>gi</td>
<td>Gaunt factor</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>HeNe</td>
<td>Helium Neon</td>
</tr>
<tr>
<td>$h$</td>
<td>Planck’s constant</td>
</tr>
<tr>
<td>IR</td>
<td>infrared</td>
</tr>
<tr>
<td>$I$</td>
<td>focal intensity</td>
</tr>
<tr>
<td>$I_{thr}$</td>
<td>threshold laser intensity</td>
</tr>
<tr>
<td>$k$</td>
<td>Boltzmann’s constant</td>
</tr>
<tr>
<td>$K_v$</td>
<td>absorption coefficient</td>
</tr>
<tr>
<td>LNG</td>
<td>liquefied natural gas</td>
</tr>
<tr>
<td>$l$</td>
<td>focal point length</td>
</tr>
<tr>
<td>MIE</td>
<td>minimum ignition energy</td>
</tr>
<tr>
<td>$n_e$</td>
<td>number of electron density</td>
</tr>
<tr>
<td>$n_{oi}$</td>
<td>population density of the $i$th ionic species</td>
</tr>
<tr>
<td>$P$</td>
<td>pressure</td>
</tr>
<tr>
<td>$P_{avg}$</td>
<td>average laser power</td>
</tr>
<tr>
<td>$P_{max}$</td>
<td>maximum laser power</td>
</tr>
<tr>
<td>PRR</td>
<td>pulse repetition rate</td>
</tr>
<tr>
<td>PRT</td>
<td>pulse repetition time</td>
</tr>
<tr>
<td>$r$</td>
<td>focal point radius</td>
</tr>
<tr>
<td>$S$</td>
<td>line strength</td>
</tr>
<tr>
<td>$t$</td>
<td>time</td>
</tr>
<tr>
<td>$T$</td>
<td>temperature</td>
</tr>
<tr>
<td>$v$</td>
<td>shock velocity</td>
</tr>
<tr>
<td>$Z$</td>
<td>partition function</td>
</tr>
<tr>
<td>ZnSe</td>
<td>zinc selenide</td>
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</table>
\( \Delta t \)
\[ \text{Pulse duration} \]

\( \Phi \)
\[ \text{equivalent ratio} \]

\( \theta \)
\[ \text{beam divergence} \]

\( \lambda \)
\[ \text{laser wavelength} \]

\( \alpha \)
\[ \text{loss coefficient} \]

\( a_o \)
\[ \text{small signal gain} \]

\( \tau \)
\[ \text{laser pulse duration} \]

\( \tau_{FWHM} \)
\[ \text{full width at half maximum (FWHM) pulse duration} \]

\( \tau_o \)
\[ \text{time at which } E(\tau_o) = \frac{E_{max}}{e}, (e = 2.7183) \text{ calculated in equation (2.4.2)} \]